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Spatial management in small-scale fisheries: A potential approach for climate change adaptation in Pacific Islands

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ABSTRACT

Small-scale fisheries are undeniably important for livelihoods, food security and income around the globe. However, they face major challenges, including global market and demographic shifts, policy changes and climate variations that may threaten the wellbeing, health and safety of fishing communities. Over the years, various forms of spatial management have been implemented in small-scale fisheries as a potential solution to problems afflicting these systems. The benefits of such approaches can be numerous for both ecosystems and coastal communities. In addition to the persistent challenges influencing small-scale fisheries practices, the emerging effects of climate change pose serious risks to coastal ecosystems and fishing communities, especially in low-lying islands. Despite a growing recognition of both the benefits of spatial management and the adverse effects of climate change on small-scale fisheries, integration of these concepts in a consistent and comprehensive way has not yet occurred. Spatial management has the potential to foster small-scale fisheries adaptation to climate change, however, in the face of such a global and transboundary phenomenon, management strategies will need to be carefully designed and implemented. First, key considerations for climate-informed spatial management in small-scale fisheries were identified. Second, these key considerations were illustrated in two selected case studies in Pacific Island countries and territories (i.e. Fiji and Papua New Guinea). Finally, the challenges associated with spatial management in a changing climate are discussed and ways forward for advancing this type of management as a climate adaptation approach for small-scale fisheries in the Pacific and beyond are proposed.

1. Introduction

1.1. Small-scale fisheries: characteristics, contribution and challenges

People around the globe, whether adjacent to coastal areas or inland, rely on marine resources as a primary source of protein, [1,2]. In addition, millions of people, including small-scale fishers, are highly dependent on these types of resources for their livelihoods and income. When compared to industrial fleets, small-scale fisheries are extremely intricate social-ecological systems that can be identified by their relatively small spatial footprint – due to fishing trips close to shore and primarily for local consumption; the diversity of gear types used; the various species targeted; and the multitude of cultures, practices and governance systems existing worldwide [1–4]. The decentralized nature of small-scale fisheries often limits the influence of governments or other governing bodies and, thus, results in informal self-governing systems or locally-specific arrangements. Despite their small spatial footprint at the local level, small-scale fisheries are major contributors to food supply, food security, employment and livelihoods globally. Small-scale fisheries employ about 90% of the fishers worldwide and supply half of the marine fish caught for human consumption [1,2,4]. In the Pacific region, small-scale fishers represent a vast majority of the population and, beyond its economic and social benefits, fishing plays an important cultural role [5,6].

While small-scale fisheries are undeniably important, they face a number of major challenges, including global market shifts, policy changes, climate variation, and demographic shifts that may threaten the wellbeing, health and safety of fishers [7–10]. In addition to the major enduring challenges small-scale fisheries face, global climate change has become an increasingly important threat to their existence. Climate change causes increases in air and ocean temperatures, rising sea levels, changes in precipitation patterns, and increasing intensity and variability of extreme events. In turn, these impacts drive changes in ecosystems upon which coastal communities depend for their livelihoods and cultures, including coastal erosion and inundation, coral bleaching, changes in fish distribution and abundance, saline

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Box 1
Common small-scale fisheries spatial management in Pacific Island countries and territories.

- Locally Managed Marine Area (LMMA)
- Community Managed Area (CMA)
- Marine Protected Area (MPA)
- Marine Reserve
- Marine Sanctuary
- Customary Tenure
- Tabu Area
- Village-based managed areas (VMA)
- Territorial User Right for Fisheries (TURF)
- Exclusive Economic Zone (EEZ)
- Marine Spatial Planning (MSP)

contamination of freshwater, increasing risk of disease, decreasing safety at sea, and disruption of fishing operations and infrastructure [4,11,12]. Climate change impacts pose particularly serious risks to low-lying islands, especially in Pacific Island countries and territories [11,13–15] due to the comparative smallness, remoteness, geographical location – close to the tropics – and archipelagic character of many of the islands [16].

1.2. Spatial management: a common practice in the Pacific

Given small-scale fisheries' deep connections with local geographies and communities' strong sense of place [17,18], various spatial management approaches have been designed and applied to small-scale fisheries (e.g., Locally Managed Marine Areas (LMMAs), Territorial Use Rights for Fishing (TURFs), and customary tenure, etc.) (Box 1) to address the problems afflicting these systems and maintain the benefits provided by the oceans [19,20]. Historically, small-scale fisheries in Pacific Island countries and territories (PICTs) have had strong connections to specific places, and communities have been using variations of traditional spatial management for many centuries [21]. The effectiveness of traditional spatial management practices, like 'tabu areas' and village-based marine reserves, in Fiji, Samoa, and Vanuatu, or 'Ahupua'a' (i.e. watershed management) in Hawai'i, for example, indicate the potential for spatial management as an approach for social-ecological adaptation [21,22]. In fact, many contemporary spatial management approaches implemented in PICTs have been largely inspired by traditional systems and incorporate existing practices. In the past few decades, hybrid systems using traditional and contemporary management methods, like Locally Managed Marine Areas (LMMA), large marine reserves or co-managed Marine Protected Area (MPA) networks, have been implemented as a way to simultaneously conserve biodiversity and livelihoods [23,24].

1.3. Spatial management: an integrated approach that benefits social-ecological systems

Spatial boundaries have long since played a significant role as delineators and dividers of institutions, management authorities, cultural identity, etc. [25]; it is thought that spatial management can make complex issues more manageable by anchoring them into specific spaces directly associated with governing and enforcing institutions, and by ascribing legitimacy and responsibility to relevant actors [20,26]. Likewise, the importance of well-defined and enforced boundaries has been extensively argued for in the common-pool resource literature as a condition for successful small-scale fisheries management [27–31]. Increasingly, such approaches have expanded in the world's oceans to define territories and delimit spaces for specific uses, practices and values. The benefits of spatial management are numerous for both ecosystems and coastal communities, such as small-scale fishers [32–36]. By allocating a specific marine area to an individual, a community, or for a specific purpose, spatial management can foster fine-scale and locally-appropriate decision-making, informed by local science and local ecological knowledge [37]. In turn, it can directly benefit habitat and resource conservation by providing potential areas in which fishery stocks can recover and spillover to surrounding fishing grounds for example, and which can mitigate the impact of uses on sensitive ecological areas [38]. In addition, spatial management has a potential to reduce current and future conflicting uses and competition over ocean space (e.g., tourism vs. fishing; small-scale vs. large-scale fishing) [39] by creating efficient spatial and temporal distribution of fishing activities [38,40]. Finally, instead of targeting a specific species, spatial approaches can offer multi-species management strategies and, hence, increase opportunities for ecosystem-based management. By providing management flexibility and opportunities to switch fisheries as a risk aversion strategy, multi-species management can increase social-ecological adaptation [38]. These management approaches can also benefit local fishery-dependent communities by supporting livelihoods and employment, protecting food security for the communities that rely on the resource as well as incentivizing sustainable fishing behaviors and ocean stewardship [41,42].

1.4. Research goal: fostering climate-informed spatial management

However, similar to other management approaches in small-scale fisheries, spatial management may not always result in expected social-ecological benefits without understanding the key considerations that foster adaptation, and carefully designing management strategies [43], especially in the context of climate change. In addition, addressing the challenges of using static boundaries to manage resources in a constantly changing world are salient efforts that can inform the development of practical and innovative climate-informed spatial management [7,44]. Now, more than ever, it is critical to design spatial management strategies that will reflect the changes and impacts driven by climate and integrate opportunities for social-ecological adaptation in Pacific Island countries and territories. In this article, key considerations for small-scale fishery spatial management in the context of climate change are identified, across learning, designing, and managing phases informed by an inductive literature review. Second, the application of these key considerations in two PICTs examples, one from Fiji and another form Papua New Guinea, are explored. Finally, the challenges associated with spatial management in the face of climate change are discussed and potential ways forward for advancing this type of management as a climate adaptation approach for small-scale fisheries in the Pacific are proposed.

2. Study method

2.1. Key management considerations

As concepts like climate change adaptation and spatial management for small-scale fisheries are gaining recognition worldwide and increasingly applied in practical management strategies and policies, it is necessary to identify key considerations for climate-informed spatial management. Early conversations took place among co-authors during a workshop held in June 2016 on small-scale fisheries and climate change in PICTs, where preliminary ideas and a set of key considerations were first drafted. In order to further highlight key management considerations, a review of several bodies of literature (i.e. climate change adaptation, small-scale fisheries governance, common-pool resource management, adaptive management and marine spatial planning) through an inductive approach was undertaken. More than 150 peer-reviewed articles were gathered by searching Scopus and Google Scholar between October 2016 and May 2017 (Supplementary Table 1). As very few articles focused on small-scale fisheries spatial management and climate change adaptation in PICTs specifically, best practices from other geographies were also included as they emerged from the search. This was not designed to be a meta-analysis of existing papers on small-scale fisheries management under a changing climate, as this is a relatively new area of research. Rather, this was a thorough review of the existing literature on small-scale fisheries management, focusing on spatial management and climate change when those themes were included in the literature.

The articles were reviewed prior to developing the final list of key management considerations, which allowed for the emergence of themes and best practices. As more articles were reviewed, the key management considerations were revised to integrate new themes and reduce overlap. Management considerations were first identified and extracted from each article and were then grouped into three larger categories that reflect important phases in the process of spatial management: (1) learning; (2) designing; and (3) managing (Fig. 1, Table 1). For each phase, a set of key considerations that reflect best practices of small-scale fisheries spatial management was identified and then, emerging themes and additional key considerations on how this type of management approach operates in the context of climate change were explored. For the purpose of this article, the key considerations presented are intended to be non-exhaustive yet comprehensive and reflect recurring themes in the several bodies of literature reviewed.

2.2. Case studies

In parallel of the literature review on key management considerations, case studies to illustrate the integration of these considerations in real-world applications were also identified. In addition, In addition, two case studies of climate-informed spatial management in PICTs small-scale fisheries are provided. While there are many examples of spatial management being used within PICTs, and a growing recognition of the need to account for climate change in small-scale fisheries management, the integration of climate knowledge into practical management is still in early stages. As a result, very few empirical examples of climate-informed spatial management in Pacific Island countries and territories (< 10 peer-reviewed articles) were found. For the purpose of this article, For the purpose of this article, case studies were intentionally chosen to reflect one initiative that has been studied multiple times and has largely achieved its goals, and one that has made less progress in order to assess how these case studies applied the key management considerations presented in this article. It is worth noting that these case studies describe an ongoing process, rather than a finalized one, and that the case studies, at the time the cited sources were written, were in varying stages along the 'learning' to 'managing' continuum.

Table 1
Two selected case studies of small-scale fisheries spatial management in Pacific Islands that illustrate how the key considerations have been applied in practice. For the purpose of this article, two case studies were examined in more details and case studies were intentionally chosen to reflect one initiative that has been studied multiple times and has largely achieved its goals (Marine Protected Area network in Kubulau District, Fiji), and one that has made less progress (Locally Managed Marine Areas in Kimbe Bay, Papua New Guinea). Key considerations highlighted in light grey are discussed and applied in the literature, key considerations highlighted in medium grey are discussed but not clearly applied, and key considerations reported in dark grey cells are not discussed at all.

Phases	*Key management considerations*	*Marine Protected Area Network in Kubulau District, Fiji*	*Locally Managed Marine Areas in Kimbe Bay, Papua New Guinea*
LEARNING	• Collecting and integrating information on social, cultural, institutional and ecological systems and understanding their interactions		✓
	• Combining diverse sources of information and knowledge (e.g. observational, experimental, and experiential) for a comprehensive and locally-relevant understanding of the system	✓	✓
	• Understanding climate-driven changes, their consequences on small-scale fisheries, and the way individuals and groups respond to them	✓	~
DESIGNING	• Identifying key stakeholders prepared to champion the management process and willing to provide a long-term commitment to help with each step of the process	✓	~
	• Defining the boundaries of the spatially managed area	✓	✓
	• Designing management strategies that are flexible and promote diversity (e.g. flexible boundaries, multi-species management, alternative livelihoods, seasonal or long-term migrations, etc.)	✓	~
MANAGING	• Ensuring monitoring and evaluation through adequate training, capacity building (i.e. education, collaborative learning, learning of new skillsets), and resources (i.e. financial (loans, funding agencies), infrastructural and institutional)	✓	~
	• Enabling fishers to be participants in the process rather than the subjects of management to ensure buy-in, self-enforcement and monitoring	~	~
	• Managing adaptively through relearning from crisis and redesigning spatial management when changes are observed or anticipated to offer new opportunities for small-scale fishers and avoid locking them in spaces where they could be at risk	✓	**X**

✓, Discussed and applied.
~, Discussed but not clearly applied.
X, Not discussed.

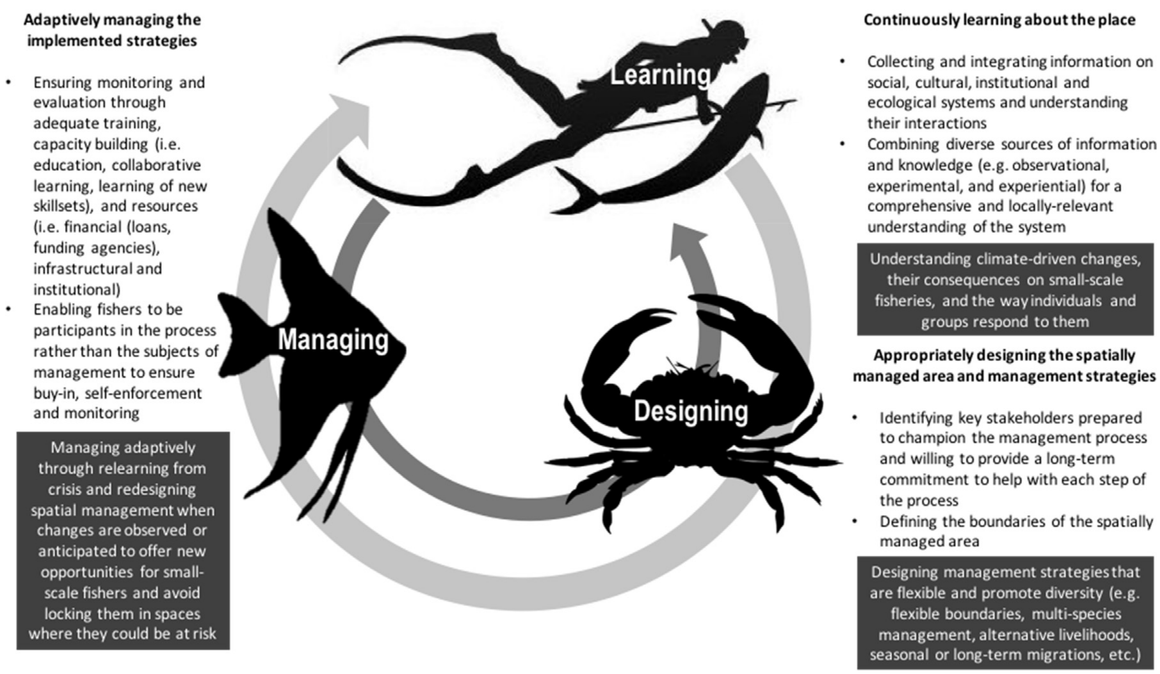

Fig. 1. Key considerations for small-scale fisheries spatial management in the face of climate change. After an extensive literature review, key considerations were identified and grouped into three larger categories that reflect important phases of the management process: learning; designing; and managing. The key considerations associated to each phase of the process are presented in this figure. The additional key considerations for implementing climate-informed spatial management are highlighted in grey boxes. The arrows demonstrate the iterative and adaptive process of successful small-scale fisheries spatial management in the face of climate change.

3. Key considerations for small-scale fisheries spatial management in the context of climate change

3.1. Continuously learning about the place

In the learning phase (Fig. 1), key considerations for small-scale fisheries spatial management emphasized in the literature involve the collection and integration of knowledge relevant to the context of the small-scale fishery. This should include information on social, cultural, institutional and ecological components at different spatial and temporal scales in order to understand their interactions and develop a comprehensive assessment of the place, ecology, and people involved in the managed area [27,29,45]. In addition, combining diverse sources of information and knowledge (e.g. observational, experimental, and experiential) is critical for a comprehensive and locally-relevant understanding of the system, and can help create a dialogue, through collaborative learning, between conventional science and traditional local knowledge [8,46,47]. Traditional local knowledge has been shown to contribute to species conservation and sustainable resource use [48] and should play a role in all aspects of managing a specific area (e.g. monitoring, adapting to changes, and understanding ecosystem processes and functions). For example, local observations of environmental and societal changes have led to a variety of traditional resource management and conservation practices in PICTs (e.g. 'tabu areas', multiple species management, resource rotation, etc.) [49–52].

Moving towards climate-informed spatial management, additional key considerations in the learning phase include understanding climate-driven changes, their consequences on small-scale fisheries, and the way individuals and groups respond to them [53]. Both conventional scientific information and local knowledge can be sources of information. For example, local knowledge on the sensitivity of different species to temperature change, scientific efforts to map the extent of climate change impacts on fisheries at different spatial and temporal scales [14], and the identification of local to global responses and adaptation strategies [7,54,55] are all relevant to increasing our rate of learning on climate adaptation in small-scale fisheries. In addition, the ability to associate and visualize, via collaborative mapping, for example, specific human responses to climate change impacts with specific social and ecological outcomes, has direct implications for identifying appropriate management responses based on analyses of trade-offs and management alternatives [56,57]. Striving for the greatest level of learning achievable will strengthen both ecological and socio-economic outcomes [36,58] in the face of climate change.

3.2. Appropriately designing the spatially managed area and management strategies

The second phase focuses on the design of the spatially managed area and management strategies (Fig. 1). An important consideration, emphasized in the literature, involves identifying key stakeholders (local or external, individuals or entities) prepared to champion the management process [8,27,29,59,60] and willing to provide a long-term commitment to help with each step of the process (e.g. collecting information, proposing management measures, monitoring, and creating linkages between various institutions). In addition, design should be a locally-controlled and deliberative process striving to reach a shared understanding and vision [61]. This should be done by identifying and involving all stakeholders, particularly the most marginalized, making space for multiple perspectives, and giving explicit attention to power dynamics to avoid increasing vulnerabilities, inequalities or human rights violations [61–63]. Once the appropriate range of stakeholders has been convened, it is necessary to define the spatial scale of management. The boundaries need to be well-defined to avoid potential conflicts about access to the resource, and the scale needs to be consistent with resource characteristics and distribution (i.e. dispersal and migration), resource user and community characteristics and the managing institution(s) [27,29,45,64,65]. Depending on these criteria, the spatial boundaries could range from a very small-scale community-managed fishing area (e.g. TURF) to a network of marine protected areas, allowing for buffer zones or periodic closures [53,66].

In the context of climate change, additional key considerations for

appropriately designing the spatially managed area and management strategies include taking into account dynamism and uncertainty of climate change impacts in the design process, allowing for more flexibility and promoting diversity. Indeed, the creation of flexible and diverse management portfolios allowing seasonal or permanent migration of individuals or fishing communities, exploring alternative livelihoods, allowing the use of multiple gears, and targeting different species all have potential as adaptive strategies [10,15]. In addition, distributing management powers and resources among organizations that operate at different spatial scales (e.g. State agencies, NGOs, fishing cooperatives, etc.) can foster adaptation by creating functional redundancy through overlap in responsibilities [67,68]. Finally, redefining boundaries when necessary such that decisions are appropriately scaled to generate desired incentives and solutions and avoid scale mismatches in the face of pressing climate change impacts will be critical [61,68–70]. Under inflexible conditions, common unintended consequences include conflicts, marginalization, poverty and often irreversible ecological shifts.

3.3. Adaptively managing the implemented strategies

The third phase describes how the implemented strategy, or set of strategies, are managed (Fig. 1). An important consideration highlighted in the literature is strong monitoring and evaluation in order to adequately respond to feedback and to sustain desirable ecosystem states [71]. The process must also ensure that adequate training, capacity building (i.e. education, collaborative learning, learning of new skillsets), and resources (i.e. financial (loans, funding agencies), infrastructural and institutional) are available or developed for the managed area [72–74]. In addition, enabling fishers to be participants in the process rather than the subjects of management by creating opportunities for self-organization or co-management efforts has been viewed as a central element to successful spatial management interventions [53,75,76]. Indeed, this could help ensure community buy-in of management interventions and increase the likelihood of self-monitoring and enforcement [27,29,46,52].

Climate change is a complex issue, but collaborative and adaptive efforts enhance the likelihood of creating social-ecological benefits even when dealing with climate impacts [46,72]. As neither natural systems nor management approaches are static, continuous and iterative monitoring, evaluation, reporting, and adaptive management are fundamental components for effective small-scale fisheries spatial management [27,29,72] Indeed, it is necessary to continuously assess the efficacy of management strategies, as well as consider social and ecological changes caused by climate change. Ongoing monitoring of environmental changes through local ecological knowledge or conventional science, when possible (e.g. resource distribution, ocean temperatures, ocean pH, habitat health, etc.), how these changes affect small-scale fishers, and how the spatial area and management strategies are also affected should be fully integrated in the process from relearning to redesigning spatial management when changes are observed or anticipated in order to offer new opportunities for small-scale fishers and avoid locking them in spaces where they could be at risk. An additional consideration for climate-informed spatial management in the Pacific would be working along with existing cultures, practices and institutions and learning from their existing adaptation strategies to provide tangible solutions to spatial management dilemmas and help develop long-term agendas for social-ecological adaptation to climate change [61]. By learning from past crises and successful adaptation, governing institutions can increase the potential for social-ecological adaptation strategies [46,53].

4. Two examples of small-scale fisheries spatial management in PICTs and their potential for climate change adaptation

4.1. Marine protected area network in Kubulau District, Fiji

The Kubulau District in Fiji is the home of an extensive network of marine protected areas, initially developed in 2005 and revised over time [77]. An update to the MPA network, undertaken to account for changes in knowledge around fishing behaviors and the impacts of climate change, is described in detail by Weeks and Jupiter [52]. This case study provides an illustration of the incorporation of climate change concerns into the management phases. Local community leaders and villagers were heavily involved in both the 'learning' and 'designing' phases (Table 1) of the marine network, through the creation of Kubulau Resource Management Committee, which included representatives from each of the ten villages affected by the spatial management plan [77]. These individuals remained key leaders during the 'managing' phase, although there is evidence that additional outreach needs to be performed to increase management effectiveness [77]. For the network revisions to incorporate climate change adaptation strategies, during the first adaptation phase (Table 1), members of the Management Committee, as well as local leaders, stakeholders, and NGOs, participated in adaptive management workshops, which presented information regarding climate change, ecological effectiveness of the current marine network, and socioeconomic impacts of the management practices [52]. These participants used this information to collaboratively design improvements to the local MPA network, seeking to increase area covered and habitats represented in order to strengthen climate change adaptation and simplify management and enforcement.

A collaborative and adaptive co-management process, involving individuals from affected communities, government, Wildlife Conservation Society (WCS), and the network's Management Committee, enabled local communities to refine spatially-explicit management strategies (in this case, an MPA network) to reflect community requirements and increased understanding of the impacts of climate change on the local marine ecosystem [52]. The national government recognizes the network as 'the main body responsible for inshore fisheries management,' which results in 'a strong policy-enabling environment for co-management' ([52]; p. 1241). While there is still progress to be made in building capacity around climate change knowledge within the local communities, this case study describes the development and revision of a climate-informed spatial management strategy and clearly reflects each of the key considerations identified in Table 1. The efforts described by Weeks and Jupiter [52] have widely integrated the key considerations, and the Marine Protected Area Network is likely to increase long-term social-ecological adaptation in Fiji's Kubulau District [58].

4.2. Locally managed marine areas in Kimbe Bay, Papua New Guinea

Our second example describes a similar process undertaken in coordination between The Nature Conservancy (TNC) and local communities in Kimbe Bay, Papua New Guinea [78]. Legal structures in Papua New Guinea provide the opportunity for creating a network of locally managed marine areas (LMMAs) that are managed at the community level. TNC is working with local communities to develop 'Plans of Management and Agreement' based on community needs and the results of a scientific planning process. To provide contrast, this example presents reflections from earlier in the process, with much of the 'managing' phase discussed but not yet realized. The 'learning' and 'designing' phases in Kimbe Bay also differed from that in Fiji (Table 1), as participants primarily included representatives from TNC, social and natural scientists, and individuals from local industry and government. Although socioeconomic surveys were conducted with local communities, and the results were considered in the scientific design, community members were not involved in the decision-making process

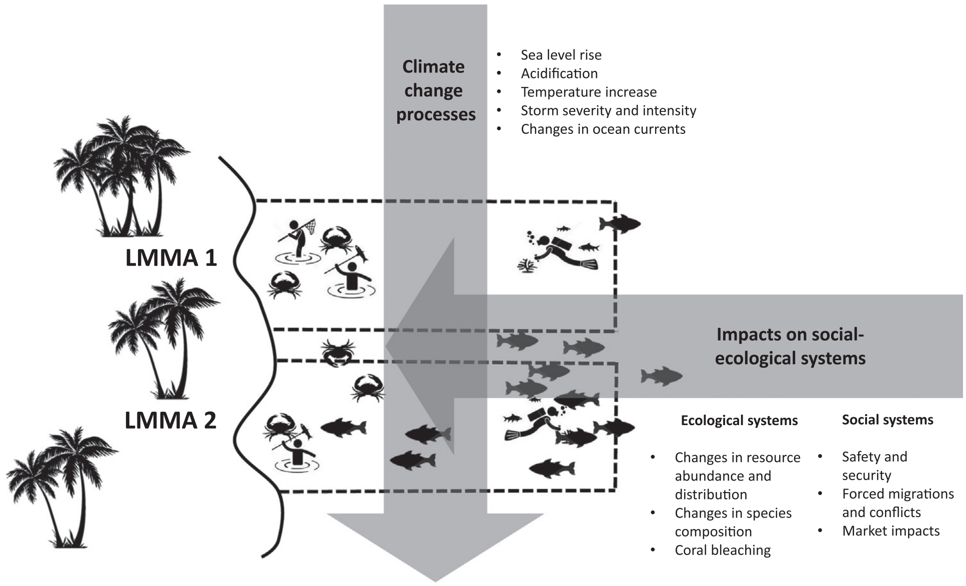

Fig. 2. Conceptual depiction of the potential impacts of climate change on small-scale fishers and the limitations of spatial management in the face of such a transboundary phenomenon. The Pacific region experiences changes in sea surface temperature, sea level rise, increased storm events, ocean acidification and many other impacts induced by global climate change sometimes resulting in shifts in the distribution of fish and changes in fish abundance. In such cases, policies and management measures that emphasize stability, certainty and top-down interventions by locking fishers into specific enclosed fishing areas via a 'Locally Managed Marine Area', for example, can decrease social-ecological adaptation and generate irreversible consequences. This figure illustrates a scenario where resources in 'LMMA' 1 experience changes in abundance and distribution, which led resources to migrate out of the enclosed area. The consequences could potentially include poaching, loss of fishing livelihoods, marginalization and conflicts over the resource between users in 'LMMA' 1 and 2 – sometimes leading to extremely violent scenarios.

until after potential MPA sites had been developed through a series of scientific workshops [78].

TNC has been working in Kimbe Bay since 1993, and the LMMA network was initially established in 2003 [79]. In 2009, the Papua New Guinea Centre for Locally Managed Areas Inc. (PNGCLMA) was created to manage the Papua New Guinea LMMA network [79]. At this same time, TNC began integrating new learning around climate change into marine network design [78]. Fine-scale knowledge regarding local climate change adaptation was not known, but 'risk-spreading strategies (representation and replication of conservation targets) and best available information' were used to develop protected sites most likely to help increase adaptive capacity for climate change ([78]; pg 496).

While this case study emphasized the broad agreement amongst NGOs and local communities about the need to protect marine resources and ecosystems, there is still uncertainty about long-term monitoring, enforcement, and integration of land-use strategies. There is also some evidence that a failure to fully integrate local community members and leaders into the management process initially resulted in locally developed managed areas that lacked clear 'managing' capacity (Table 1), and were thus insufficient to achieve social-ecological outcomes [80,81]. TNC is continuing to work with local communities to improve the effectiveness of the LMMA network.

Although the two case studies presented in this section are themselves spatially explicit, they do not necessarily reflect management practices across all PICTs. However, they do provide a starting point for further reflection and discussion and illustrate the application of the key considerations in practice by emphasizing current climate-informed practices and areas of improvement.

5. Discussion: can spatial management be a potential approach for climate change adaptation in small-scale fisheries?

Climate change is adversely affecting small-scale fisheries in Pacific Island countries and territories [14]. Effective management solutions are critical for enhancing climate change adaptation strategies [82] that alleviate adverse effects on ecological, social and economic systems and take advantage of new opportunities [83]. Climate change adaptation can take many forms, using diverse strategies undertaken by individuals, groups or by governments, and can be motivated by many factors and desired outcomes (e.g. preserving economic opportunities, maintaining well-being or livelihoods, improving safety or conserving resources) [4,72,84]. By definition, climate change is a dynamic, transboundary and uncertain phenomenon [85], and increasing the diversity and flexibility of spatial management has potential to offer small-scale fishers and governing institutions an approach for climate change adaptation. Here, the several challenges that will need to be addressed and the innovative solutions that will need to be integrated into management strategies for climate-informed spatial management to support small-scale fisheries adaptation are discussed.

5.1. *The issue of a bounded approach in the context of a transboundary phenomenon*

The use of management approaches or policies based on static boundaries in the context of a transboundary phenomenon like climate change poses serious issues and limits potential adaptation strategies. In addition, the complexity of social-ecological interactions inherent in small-scale fisheries systems and the uncertainty of climate change impacts make practical climate-informed spatial management challenging to design and implement [86–88]. While conventional spatial management has proven to be a successful approach for small-scale fisheries in specific contexts, many challenges remain to be addressed in the context of a transboundary phenomenon such as climate change.

In the next few decades, the Pacific region will likely experience changes in sea surface temperature, sea level rise, increased storm events, ocean acidification and many other impacts induced by global climate change [12,89]. First, as these phenomena increase in frequency and severity, shifts in the distribution of fish and changes in fish abundance will co-occur [14,90]. In such cases, policies and management measures that emphasize stability, certainty and top-down interventions by locking fishers into specific enclosed fishing areas, via TURFs or MPAs for example, can decrease social-ecological resilience and generate consequences that may be difficult – if not impossible – to reverse (Fig. 2). This may be especially true if the abundance of commercially or culturally important marine species in the spatial management area declines. Attendant adverse consequences for fishing communities may include population migrations, poaching, marginalization and conflicts – sometimes leading to extremely violent scenarios [91,92].

Second, a significant barrier to successful spatial management include spatial mismatches between human uses and governance systems with respective marine resource distributions (due to dispersal and migration) [64,93] leading to inefficient management efforts and threats to the health of ecosystems and fishers' wellbeing. Numerous examples show the repercussions on social-ecological systems such as decreasing adaptive capacity and fishing livelihoods due to a reduction

or restriction of traditional fishing spaces [94], exacerbation of non-compliance by fishers who are seen as poachers or unwanted migrants [95], or human rights violations [20,96]. Ecologically, boundary mismatches have been shown to create an added pressure on fish stocks, giving rise to serial overfishing at the regional-global scale as well as localized depletions in border areas [97,98].

Uncertainty in regards to climate-induced processes and how they may impact small-scale fisheries remains a management challenge [85]. The inability to predict surprises and the uncertainty of the data around local climate change impacts, as well as the lack of capacity (e.g. infrastructure, staff, financial) in many of these areas increases the difficulty of climate-ready small-scale fisheries management. Additionally, the array of adaptation strategies available to small-scale fishers on islands and atolls might be more constrained than communities on large continents, due to the remoteness and small spatial footprint available of these islands.

5.2. Moving towards climate-informed spatial management for small-scale fisheries

To address the many challenges described in the previous paragraphs, innovations in spatially-explicit management approaches that foster adaptation to climate change should be considered. Importantly, in any future climate-informed spatial management plan, carefully integrating the key considerations described in this article in a more consistent and comprehensive way is essential to enhance climate change adaptation in PICTs. Indeed, successful spatial management of small-scale fisheries is an involved and potentially complicated process and it is dependent on a thorough understanding of the social-ecological system, including local culture, formal and informal governance systems, fishing behaviors, existing adaptation strategies, and advanced knowledge of the marine environment itself.

The first two phases, ‘learning’ and ‘designing’, are crucial to ensuring that the spatial management system is appropriate for the local context and is effective for both the human and ecological components of the system [77]. For example, legislation may include officially devolving management responsibility to community-level governance bodies and legislative recognition of ‘tabu areas’ with government assistance or training for management and enforcement. In addition, working directly with local communities though an inclusive and deliberative process to design, implement, and manage the system can help to develop a sense of ownership over the project, improve the likelihood of achieving desired social and ecological outcomes, and strengthen the adaptation stage given small-scale fishers’ extensive knowledge of their environment and experience with past change. In fact, social-ecological systems in Pacific Islands have historically been able to adapt to environmental change. Empirical studies show that people have adapted to short-term impacts [15,99,100] as well as longer-term environmental perturbations [49–51,101] via a range of locally-appropriate practices. For example, alternative livelihoods can be drawn on to adapt to declining fish yields when cultural identities connected with fishing allows it [102,103].

Moving forward, ensuring that adaptive management is facilitated will be critical [47]. Responding to climate change will require adjustments in governing and managing institutions that allow them to be more dynamic and flexible and offer a diverse portfolio of management measures. For example, species and gear diversification as a risk aversion strategy has been proven to enhance adaptation of both social and ecological systems [10]. In addition, the very idea of firm and static boundaries will need to be rethought to reflect the transboundary processes and effects of climate change. Song et al. [20] proposes initial steps for recalibrating the approaches for designating spatial boundaries in small-scale fisheries management and argues that ‘re-incorporating, re-scaling and re-imagining boundaries can invite varied and context-driven configurations of organizing fishery interactions’. This will help to ensure a match between the multiple kinds of boundaries (i.e., social, ecological and institutional) in a continuous, adaptive and collective way that takes into account the perpetually shifting and socially-ecologically linked nature of small-scale fisheries system and climate change [104].

Finally, researchers, practitioners and decision-makers will need to continue to think about innovative, applicable and inexpensive solutions to respond to climate change impacts. For example, the scientific community has been introducing the idea of enhancing traditional spatial management with dynamic ocean management, which allows protected areas to move in response to changing conditions over various time scales, including daily, seasonally, annually or longer timeframes. This type of approach provides the flexibility to incorporate small-scale changes in near real time, as well as the large-scale shifts resulting from climate change and inter-annual variability in the marine environment [104–106]. In addition, joint fishing zones or transboundary conservation areas [107], more flexible harvest plans for shared or migratory fish stocks [108], and MPA networks linking fragmented small reserves have been explored to increase connectivity and opportunities for greater social-ecological adaptation. Although these new concepts seem attractive in theory, in order to design and implement such spatial management measures in practice one must first confront the challenges that may arise due to the rigidity of certain governing systems, a lack of resources and inter-regional cooperation.

In conclusion, spatial management could play a key role in facilitating the development of adaptation strategies in the face of climate change, but is not a panacea. The uniqueness of each region, which is determined by a set of social-ecological processes and interactions, means that there is no ‘one-size-fits-all’ spatial management example of best practice. However, spatial management that focuses on integrating the key considerations presented in this article, by continuously learning about the social-ecological context of the managed area, appropriately designing the spatially management area, and adopting a more flexible and diverse portfolio of management measures that allows for adapting to observed or foreseen climate change impacts, will be more likely to address new challenges as they arise. Finally, rethinking the very idea of spatial boundaries as a fixed approach to reflect the transboundary and dynamic nature of climate change will be critical to enhance small-scale fisheries adaptation and foster effective solutions in the Pacific islands’ waters and beyond.

Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2017.09.030.

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